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REVIEW ARTICLES

Status Analysis and Development Suggestions on Signaling System of Beijing Rail Transit

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Abstract The current statuses on signaling system of Beijing rail transit, including the signaling devices, repair and maintenance, spare parts, and personnel training, were investigated and presented in general. The existing issues were also presented. Considering the development of Beijing rail transit in future, some suggestions are proposed to the local government for Beijing rail transit in future development.

Keywords Beijing subway · Rail transit · Signaling system · Status analysis · Development suggestions · Maintenance · Spare parts · Personnel training

1 The Overview of Beijing Rail Transit

In 2013, the passenger flow of Beijing rail transit network presented a rapid growth. The passenger traffic reached 3.205 billion in the whole year, i.e., 8.78 million per day, with year-on-year growth of 30.54 %. Specifically, over the weekly period, the passenger traffic reached on average 9.489 million per day; the largest number of passenger traffic per day reached 11.055 million. Rail transit plays an important role in easing the pressure of ground traffic jam.

At present, Beijing rail transit systems are operated by Beijing Subway Corporation Limited (Beijing Subway) and Beijing MTR (Mass Transit Railway) Corporation Limited (BJMTR).

Beijing Subway, with 29,117 employees, is a professional oversized, state-owned operator focusing on managing the operating lines of urban rail transit; its predecessor is Beijing Underground Railway Corporation. At present, lines operated by this company include Line 1, Line 2, Line 5, Line 6, Line 8, Line 9, Line 10, Line 13, Line 15, Ba tong Line, Airport Line, Fang shan Line, Chang ping Line, and Yizhuang Line. The company operates 231 stations, with its total operating distance reaching 395 km.

Mass Transit Railway, established in January 2006, is the first corporative venture which introduced foreign capital in domestic urban rail transit field. The funding contributors of this company are Beijing Infrastructure Investment Corporation Limited, accounting for 2 %; and Beijing Capital Group and MTR Corporation Limited, accounting for 49 % each. The company has 4680 employees, operates Beijing Metro Line 4, Da xing Line, and Line 14; its total operating distance coverage is 62 km. Table 1 illustrates the overall operating statuses of the two companies and the operating situation of each line.

Table 2 illustrates the operating condition of each metro line).

2 The Current Situation of Signaling Systems and Equipments

As a component of technical equipment which ensures safe, punctual, fast, convenient, high-density, ceaseless operation of the train, signaling system plays an important role in rail transit system [1–3]. The signaling system consists of four subsystems: automatic train supervision

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Table 1 Overall operation status of Beijing rail transit

Items	Beijing subway	BJMTR	Total
Operating distance/km	403	62	465
Numbers of stations	235	41	276

system (ATS), automatic train protection subsystem (ATP), automatic train operation (ATO), and computer-based interlocking subsystem (CI). The four subsystems form a closed-loop system via message switching network—automatic train control (ATC) that manages to combine ground-control and train-control, local control, and central control together. In order to facilitate safety in operation, an ATC system which integrates the functions of traffic control, operating adjustment, and automatic driving is constructed. The signaling system operates in modes of distributed management and centralized control. Distinguished from the distribution of section, the centralized signaling system is made up of controlling equipments in the center, station equipments, vehicle-based equipments, trackside equipments, and on-board equipments.

ATC has two kinds of classification: (1) According to the classification of block systems, it can be divided into fixed block, quasi-moving block, and moving block; (2) According to the classification of train–ground communication, it can be divided into continuous and point models.

Fixed block ATC system is an automatic block system based on traditional rail circuit. Based on line conditions, the block section is confirmed by traction calculation. Once confirmed, the section would be permanent. The train's tracking intervals are divided into several block sections, which is irrelevant to the train's actual location in the section. The starting point and terminal point are usually considered to be the boundaries of certain section. Train-tracking diagram is shown in Fig. 1.

Quasi-moving block ATC system is also an automatic block system based on traditional rail circuit. The trains' interval is estimated and controlled by the safety margin plus the succeeding train's braking distance at the present speed. The block section occupied by the front train is protected from being advanced rashly. The starting point of braking is dynamic, the terminal point is fixed within the confines of a certain section. Train-tracking diagram is shown in Fig. 2.

Moving block ATC system incorporates medias, such as wireless communication, ground cross-induction loop line, and waveguide, to help transmit information to the mobile unit. The safe train interval is calculated according to the information of maximum permitted speed, the present docking station, and the operating line. The information is updated cyclically to ensure that the train receives instant message ceaselessly. By using the bi-directional data communication equipment between the train and the

Table 2 Operation status of each line

Lines	Passenger capacity (ten thousand person-time)	Design interval	Actual operation interval	Operation all day ranks (number)
Line 1	142	2 min	2 min 05 s	725
Line2	137	2 min	2 min	611
Line 5	98	2 min	2 min 30 s	562
Line 6	61	2 min	3 min	410
Line 8	24	3 min (transition system)	3 min 30 s	308
Line 9	40	2 min	4 min	382
Line 10	190	2 min	2 min 15 s	670
Line 13	86	3 min	2 min 40 s	525
Line 15	14	2 min	6 min 15 s	245
Ba tong line	34	4 min	2 min 50 s	434
Fang shan line	9	3 min	6 min	280
Chang ping line	15	2 min 30 s	5 min 30 s	263
Yizhuang line	18	2 min 30 s	5 min 50 s	246
Airport line	3	4 min	8 min 30 s	222
Line 4	128	2 min	2 min (peak period, one-way 1 min 43 s)	Ordinary days: 622: two-day weekend: 556
Da xing line	31	2 min	4 min	
Line 14	6	4 min (the first-period project, 12 km)	5 min (the first-period project)	Ordinary days: 362 two-day weekend: 372

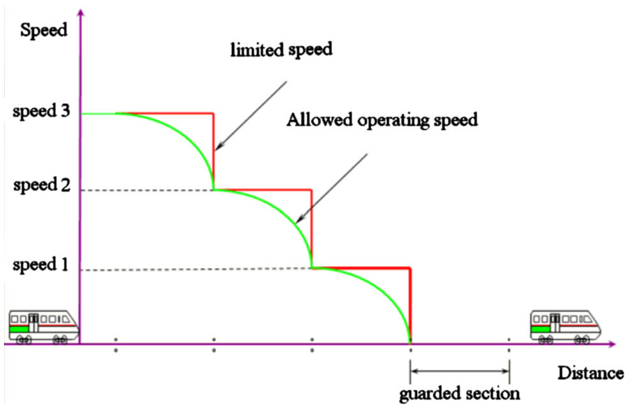

Fig. 1 Train-tracking diagram of fixed block system

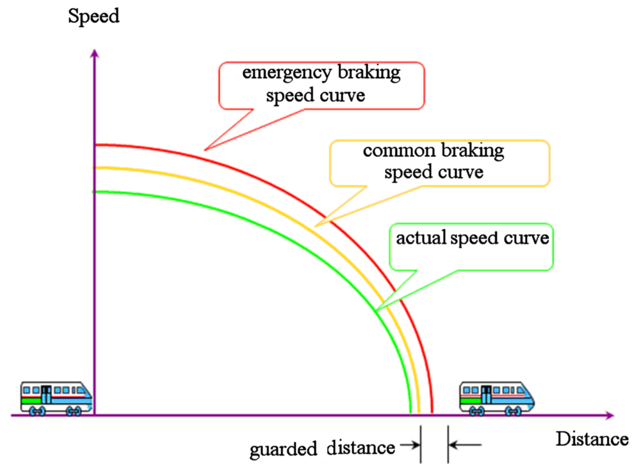

Fig. 3 Train-tracking diagram of moving block system

ground, the ground signal equipment can get continuously the information of each train's current location. According to the information, the operating permissions of each train can be calculated, and dynamic updated information would be sent to the train. The train calculates the operating velocity curve according to the received information of operating permission and its own operating state, and then it can implement a complete-protection mode of train operation. The braking starting point and terminal point are dynamic. It is more advantageous for providing full play of rail capacity. Train-tracking diagram is shown in Fig. 3, monitoring the differences in guarded distance which is dynamic and shorter than that in Fig. 2.

The biggest difference among fixed block ATC system, quasi-moving block ATC system, and the moving block ATC system is the control over train's safety interval. Each line's signaling system's basic condition is compiled in Table 3.

At present, there are several types of the signaling systems which are operating online in Beijing.

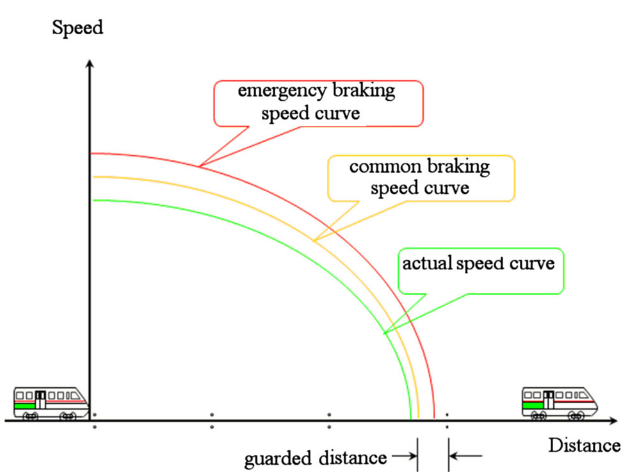

Fig. 2 Train-tracking diagram of quasi-moving block system

(1) Multi-systems coexist with each other. In light of the various technical levels of different constructing times and the different technical updating levels after being put into operation, there are multiple systems that coexist in Beijing's subway signaling system: Line 1, Line 13, and Ba tong Line belong to the fixed block ATC system; Line 5 belongs to quasi-moving block ATC system; and Line 2, Line 6, Line 8, Line 9, Line 10, Line 15, Yizhuang Line, Chang ping Line, Fang shan Line, Airport Line, Line 4, Da xing Line, and Line 14 all belong to moving block ATC system. Due to the large passenger traffic capacity and operating demand, the situation of coexistence of multiple systems would last for a relatively long time in Beijing's rail transit signaling system. As for the situation, the crucial problem faced by operating companies is that there is a wide range of trackside equipments and on-board equipments which differ from each other and they cannot be used universally, i.e., uniformly as different patterns of signaling systems coexist. Even if the systems share a same pattern, products from different manufacturers cannot be used universally. Therefore, for Beijing Subway, which operates many rail lines, the manufacturing of spare parts and updating instruments for each line would pose huge challenges. Furthermore, most of the equipments of fixed blocking system and quasi-blocking system are based on single-configuration—once signaling system's operation is influenced by faults, the whole normal operating process would be severely affected. This would bring huge pressure on the company in terms of daily repair and maintenance works of the signaling system.

(2) Coexistence of multiple suppliers. At present, there are more than ten suppliers who participate in the subway signaling system operations via bidding competition. Most of them are overseas-funded

Table 3 Signaling system's basic condition of each line

Lines	System mode	Backup mode	ATP supplier	ATO supplier	ATS supplier	Interlock supplier	Opening time of existing system/year
Line 1	Fixed block (speed step)	No	Westinghouse	No	CASCO	Electric relay interlocking	1993
Line 13	Fixed block(speed step)	No	Westinghouse (Dacheng)	No	CASCO	Academy of railway sciences	2002
Ba tong line	Fixed block (speed step)	No	Westinghouse (Dacheng)	No	CASCO	CRSC	2003
Line 5	Quasi-moving block (target-distance)	No	Westinghouse (Dacheng)	Westinghouse (Dacheng)	CASCO	CASCO	2007
Line 2	Moving block	Point ATP/ATO	Alston (CASCO)	Alston (CASCO)	CASCO	CASCO	2008
Line 6	Moving block	Point ATP/ATO	Alston(CASCO)	Alston(CASCO)	CASCO	CASCO	2012
Line 9	Moving block	Point ATP/ATO	Alston(CASCO)	Alston(CASCO)	CASCO	CASCO	2011 (south of the line opened), 2012 (all opened)
Fang shan line	Moving block	Point ATP/ATO	Alston (CASCO)	Alston(CASCO)	CASCO	CASCO	2010
Airport line	Moving block	No	Alston (CASCO)	Alston(CASCO)	CASCO	CASCO	2008
Line 10	Moving block	Point ATP/ATO	SIEMENS (railway signal communition corp)	SIEMENS (railway SignalCommunitionCorp)	SIEMENS (railway SignalCommunitionCorp)	SIEMENS (railway signal communition corp)	2008
Line 8	Point ATP/ATO	No	CRSC	CRSC	CRSC	CRSC	2011
Line 15	Moving block	Point ATP/ATO	Nippon signal (Jiaodamicrounion Tech. Co. Ltd.)	Jiaodamicrounion	Jiaodamicrounion Tech. Co. Ltd.	Jiaodamicrounion Tech. Co. Ltd.	2010
Yi zhuang line	Moving block	Point ATP/ATO	Traffic control technology	Traffic control technology	CASCO	CASCO	2010
Chang ping line	Moving block	Point ATP/ATO	Traffic control technology	Traffic control technology	CASCO	CASCO	2010
Line 4	Moving block	No	Thales Canada	Thales Canada	Thales Canada	Main track: Thales Canada; rail yard: Academy of railway sciences	2009

Table 3 continued

Lines	System mode	Backup mode	ATP supplier	ATO supplier	ATS supplier	Interlock supplier	Opening time of existing system/year
Da xing line	Moving block	No	Thales Canada	Thales Canada	Thales Canada	Main track: Thales Canada; rail yard: Academy of railway sciences	2010
Line 14	Moving block	Point ATP/ATO	Traffic control technology	Traffic control technology	CASCO	CASCO	2013

enterprises and joint-venture enterprises, while a few of them are independent domestic enterprises (less than 10 %). Objectively speaking, bidding competition for multiple suppliers is beneficial for reducing cost during the initial stage of construction; however, it is very disadvantageous for the cost control of entire life-cycle and is harmful for the operating management. According to our survey, overseas manufacturers usually employ strong research teams, have huge production capacity, and have overwhelming advantage in core technology. However, in the aspects of after-sales service, spare parts supply, and rapid emergency response, overseas manufacturers rely on local team's construction. Generally speaking, most overseas manufacturers perform well and render perfect service, but domestic manufacturers have prominent advantages in providing technical support, repair and maintenance, and rapid emergency response [4–6].

(3) The signaling system cannot open up all its functions when most lines start to operate. Being the capital of China, Beijing suffers from huge pressure of ground traffic as the combined urban and floating population is huge. Rail transit with large capacity and high efficiency is an important way of relieving the ground traffic pressure. Due to the short period of new line's construction and trial operation, subway lines' signaling system does not fulfill the condition of opening up full-functions. Here are the results: (1) Due to the shortage of time of debugging system's equipments, the functions are not implementable fully, which leads to unstable operation. (2) The system is updated too frequently after being put into operation, while some suppliers do not prepare well for updating.

(4) Signaling system's fault occurrence is inevitable. Signaling system's operating performance is not only influenced by equipments, but it is also related to running intervals, and the efficiencies of maintaining technician and assistants in dealing with faults. As there are various influencing factors, it is impractical and technically impossible for signaling system to realize "zero defect" and "zero risk".

3 The Condition of Equipment Repair and Maintenance

Despite following different managing mechanisms, both the above companies have strict institutions of equipment repair and maintenance. The signaling system equipments of the present 14 operating lines of Beijing Subway are maintained by its Communication signal branch company. The company follows a combined pattern of plant maintenance, status maintenance, and breakdown repair. The maintenance working schedule for the next year would be laid down by the company in the end of each year in order to complete the works of inspection, touring and maintenance. BJMTR has introduced the managing mechanism of MTR, which includes preventative maintenance and fault repair. Whether the equipment is within the quality guarantee period or not, the company would implement preventative maintenance regularly. At present, the preventative maintenance working plan directs the daily maintenance section which covers all the signal facilities completely. The employees follow those guidance rules to carry out the preventive maintenance work. When carrying out the fault repair work, if the facility is still within its quality guarantee period, the employees of BJMTR would point it out first, and notify the contractor to provide support if necessary. If the facility is beyond its quality guarantee period, the repairing work would be implemented by BJMTR employees.

4 The Condition of Spare Parts

In general, the newly built metro line would receive spare parts by following the stipulated percentage of construction contract, and apply them to use after the expiry of the system's quality guarantee period. According to the actual needs, the subway company would adjust the variety and the quantity of the spare parts, then follow the plan to buy more (exclusive capital would be allotted for those buying plans). The spare parts of key signaling system of BJMTR would be stored in concentrator station, and the related configuration would be completed beforehand, so that the replacing time could be minimized. The situation of the spare parts sites would be monitored daily, and spare part replenishment would be made at any time if necessary. According to various factors such as the number of facilities, the rates of fault incidences, and the supply/delivery periods, the signal department would manage to maintain the level of spare parts inventory reasonably, and review at regular intervals to obtain timely replenishment. Current problems are listed as follows:

(1) The total stock quantity of the spare parts received according to the stipulated percentage of the contract is relatively small, which leads to the severe shortage of spare parts of the operating company and affects the normal operation of the system.
(2) Due to the various electrical parts of the signaling system facilities and the rapid rate of replacement, some lines have encountered the situation of former model's production coming to a halt, such as Line 4.
(3) At the start of operation of certain newly built signaling systems, the suppliers do not comply with providing full range of complete instruments and software that can maintain the system, which leads to severe constraints in running the normal operation.
(4) After some lines of the signaling system come into operation, the rate of update is frequent, but the updating spare parts provided by the supplier fall short of actual requirement.

5 The Training of Employees

The operating companies all have strict training programs for signal operators. Beijing Subway has established a specialized base for Signaling system training courses, and conducts various forms of training, such as enlarged class, training given by the manufacturers, tutorial system, and theme training. Before the induction, professional signal maintainers should receive specialized training and get the certificate of qualification. During the working period, advanced training of operation skill would be provided according to plans, so that employees' skills would be improved. Competitions and examinations on operating procedures would be conducted at regular intervals. The operating level of employees would be judged according to the fixed programs.

The training program for the employees in BJMTR includes the following:

(1) For the new employee, in order to ensure the safety of production, induction training and safety education would be organized.
(2) During the probation period, the new employees would take fixed post's training, and only if they pass the training test they can work formally with certificates.
(3) The employees should receive training provided by suppliers.
(4) Professional maintenance department and company's training department review the professional knowledge levels of technicians, and organize related training.
(5) Generalizing the key experience of dealing with faults every month, and organizing exchange activities.
(6) Organizing exams at regular intervals, finding the problems, and providing specialized training. Besides, the signal repair department would conduct assessment of occupational skills, and analyze the weakness of every employee, and arrange for specialized training, so that the employees would have deeper understanding of the signaling system. The company would illustrate the working mechanisms of different functional patterns, and make its employees concentrate on the ideas of investigating faults in the signaling system. At the same time, the company would allow its employees to take part in the training provided by the suppliers.

The most crucial problem currently is the commitment of the personnel. In order to grasp the operation of each line craftily, the professional maintenance technicians need skill training for a long time as the multistandard signaling systems coexist with each other. However, many technicians would leave their jobs after specialized long-duration training. Strong guarantee of institutional support and payment is very important for forming a committed and loyal team of signaling system technicians.

The impending question is whether the demand of signal technicians can be met in the future or not. There is an analytic report of the present status of Beijing Subway: there are five senior engineers, 21 engineers, 61 associate engineers among the technician team, and with 0.22 person per kilometer, the team presents a pyramid-like structure, but the staff strength of the team is relatively small. There are five senior technicians, 25 technicians in the signal technicians team, and 0.07 person per kilometer, accounting for 2.99 % of the total staff strength. Compared with the actual percentage, 9.3 %, of Beijing's talent team building, the total percentage of signal technicians is relatively small. With the rapid growth of operating mileage, the percentage of new employees' growth would decline further, which cannot meet the demands of the present and future. If we estimate that Beijing's rail transit distance coverage would reach 900 km in 2020, the reasonable percentage of engineering and technical staff in the signal team should be 1 person per kilometer (exchanging posts is permissible), and the total staff number should be 900. The technical staff should make up 10 % of the total employee strength. According to the present estimate, Beijing Subway and BJMTR should employ 2900 and 460 technical staff each.

6 The Current Situation and Performance of ATC

Here is the current list of the main suppliers of Beijing's online signaling system: Alston (CASCO), SIEMENS (Railway Signal Communication Corp), The Nippon Signal Co. Ltd (Jiaodamicrounion Tech. Co. Ltd), Traffic control technology Co. Ltd. Bombardier provide the moving block ATC system; SIEMENS, Westinghouse (Dacheng), CASCO, and Bombardier provide the quasi-moving block ATC system; Westinghouse and China Railway Signal & Communication Corporation research and design institute (CRSC) provide the fixed block ATC system. Domestic companies which provide interlocking facility are the Academy of Railway Sciences, CRSC, and CASCO.

Table 4 shows the comparison and summary of the ATC system equipments, including all the present subway lines. On summarizing and comparing equipment conditions and main performances of the ATC systems of the present metro lines, we found that signaling systems provided by various suppliers do not have a uniform standard, either domestic or overseas. Although the systems share the same principle and function, they differ from each other in controlling, interface mode, and system's structure. Systems of different suppliers and models are not compatible with each other. Different maintenance facilities and spare parts cannot be applied universally.

According to the survey, however, domestic techniques of signaling system and equipment's management level are close to general international level. Specifically, it demonstrates that the *Two as average train kilometer between accidents delayed more than 5 min* ranks among the top of OMET members. The equipment fault rate is 0.088 piece/10,000 km (the international standard of which is 0.8 piece/10,000 km), which is much lower than the international standard.

7 Suggestions for Development

(1) Implementing uniform formats of signaling system. As long as we follow the principles of safe operation, different signaling systems will all have alternative choices all over the world. [7, 8] In the future, safety and reliability are still the priorities in the choice of signaling systems in signal transit field where safety is highly important. Although the moving block signaling system is relatively advanced, we suggest that moving block signaling system be applied to the modification of the existing lines and the construction of new lines gradually.

(2) Creating a uniform standard of equipments. Departments concerned with subway, such as investment, construction, design, operations, and management, should coordinate with each other, and take various factors into full account to make integrative plans. In the process of selecting models and updating software and hardware, with due consideration of the ability of managing, operating, repairing, and maintaining, the company can formulate the demand standard of system; set up large database; establish norms of user-requirement-oriented ATC system; construct uniform device interface of modularized management; carry out system's acceptance criteria; consider a uniform standard of maintenance and repair; and improve the collaborative guaranteeing mechanism of constructing, managing. and manufacturing.

(3) Controlling signaling system suppliers' number, appropriately, strengthens the management and enables restriction in the number of system suppliers. In after-sales service, on the basis of constructing norms, the company should adopt standardized and universal products for the convenience of daily repair and maintenance. Besides, through signaling

Table 4 The ATC system equipments' comparison and summary of each line of Beijing Rail Transit

Lines	Line length/km	Stations numbers	Numbers of ATC equipment interlocking control centers	Train detection system	The locomotive signaling system	TWC (train-ground communication) mode	On-board ATP redundancy mode	On-board ATC equipment	ATO system speed control mode	ATO system station locates the parking control mode	ATS subsystem
Line 1	31.58	23	23	Track circuit consist of send plate, after closing, weaving/code circuit, code generator, tuning unit, etc.	Speedometer, on-board computer, interface relays, speed motor, antenna, etc.	One-way communication from ground to train of track circuit	No head to tail redundancy	Speedometer, on-board computer, interface relays, speed motor, antenna, etc.	No ATO	No ATO	Consist of central server, local ATS extension, local workstation, OCC workstation, maintenance workstation by DCS network
Line 13	40.5	16	16								Consist of central server, local ATS extension, local workstation, OCC workstation, maintenance workstation by DCS network
Ba tong Line	17.2	13	13								Consist of central server, local ATS extension, local workstation, OCC workstation, maintenance workstation by DCS network
Line 5	27.6	23	10	Track circuit consist of TCOM computer, send plate, after closing, weaving/code circuit, code generator, tuning unit, etc.	Speedometer, on-board computer, interface relays, speed motor, doppler radar, beacon antenna, etc.	One-way communication from ground to train of track circuit, two-way communication of BIDI wireless	Head to tail redundancy	Speedometer, on-board computer, interface relays, speed motor, doppler radar, beacon antenna, etc.	Receive the ground speed code, control the speed according to the operating curve	Positioning according to the electronic map and the ground parking beacon. Accuracy of plus or minus within 300 mm	Consist of central server, local ATS extension, local workstation, OCC workstation, maintenance workstation by DCS network

Table 4 continued

Lines	Line length/km	Stations numbers	Numbers of ATC equipment interlocking control centers	Train detection system	The locomotive signaling system	TWC (train-ground communication) mode	On-board ATP redundancy mode	On-board ATC equipment	ATO system speed control mode	ATO system station locates the parking control mode	ATS subsystem
Line 2	23	18	7	Axle counter consist of head, outdoor control box, axle host, etc.	\	Two-way communication from ground to train through waveguide wireless	Head to tail redundancy	On-board computer, human–machine interface, interface relays, code odometer, beacon antenna, etc.	Accurate positioning through the electronic map, speed motor and ground beacon, and control train SAcceleration, cruise, braking and parking under ATP protection curve	Positioning according to the electronic map and the ground parking beacon, and correct parking control curve timely. Accuracy of plus or minus within 300 mm	Consist of central server, local ATS extension, local workstation, OCC workstation, maintenance workstation by DCS network
Line 6	30.69	20	7			Two-way communication from ground to train through waveguide wireless	Head to tail redundancy	On-board computer, human–machine interface, interface relays, code odometer, beacon antenna, etc.			consist of central server, local ATS extension, local workstation, OCC workstation, maintenance workstation by DCS network
Line 9	16.5	13	6			Two-way communication from ground to train through waveguide wireless	Head to tail redundancy	On-board computer, human–machine interface, interface relays, code odometer, beacon antenna, etc.			Consist of central server, local ATS extension, local workstation, OCC workstation, maintenance workstation by DCS network
Fang shan Line	24.7	11	5			Two-way communication from ground to train through waveguide wireless	Head to tail redundancy	On-board computer, human–machine interface, interface relays, code odometer, beacon antenna, etc.			Consist of central server, local ATS extension, local workstation, OCC workstation, maintenance workstation by DCS network

Table 4 continued

Lines	Line length/km	Stations numbers	Numbers of ATC equipment interlocking control centers	Train detection system	The locomotive signaling system	TWC (train-ground communication) mode	On-board ATP redundancy mode	On-board ATC equipment	ATO system speed control mode	ATO system station locates the parking control mode	ATS subsystem
Airport Line	28.1	4	4			Two-way communication from ground to train through waveguide wireless	Head to tail redundancy	On-board computer, human–machine interface, interface relays, code odometer, beacon antenna, etc.			Consist of central server, local ATS extension, local workstation, OCC workstation, maintenance workstation by DCS network
Line 10	57.1	45	14			Two-way communication of wireless free-field waves	Head to tail redundancy	On-board computer, human–machine interface, interface relays, speed motor, doppler radar, beacon antenna, etc.			Consist of central server, local ATS extension, local workstation, OCC workstation, maintenance workstation by DCS network
Line 8	20	13	5			Two-way communication of wireless free-field waves	Head to tail redundancy	On-board computer, human–machine interface, interface relays, speed motor, doppler radar, beacon antenna, etc.			Consist of central server, local ATS extension, local workstation, OCC workstation, maintenance workstation by DCS network
Line 15	30.5	13	4			Two-way communication of wireless free-field waves	Head to tail redundancy	On-board computer, human–machine interface, interface relays, speed motor, beacon antenna, GPS antenna, etc.			Consist of central server, local ATS extension, local workstation, OCC workstation, maintenance workstation by DCS network
Yizhuang Line	23.3	14	6			Two-way communication of wireless free-field waves	Head to tail redundancy	on-board computer, human–machine interface, interface relays, speed motor, doppler radar, beacon antenna, etc.			Consist of central server, local ATS extension, local workstation, OCC workstation, maintenance workstation by DCS network
Chang ping line	23	7	3			Two-way communication of wireless free-field waves	Head to tail redundancy	on-board computer, human–machine interface, interface relays, speed motor, doppler radar, beacon antenna, etc.			Consist of central server, local ATS extension, local workstation, OCC workstation, maintenance workstation by DCS network

Table 4 continued

Lines	Line length/km	Stations numbers	Numbers of ATC equipment interlocking control centers	Train detection system	The locomotive signaling system	TWC (train-ground communication) mode	On-board ATP redundancy mode	On-board ATC equipment	ATO system speed control mode	ATO system station locates the parking control mode	ATS subsystem
Line 4	28	24	8	Axle counter equipment, beacon	VOBC	Train-ground communication through wireless access point	Three choose two in key parts	VOBC cabinet, TOD, speed sensors, proximity sensors, TI antenna, wireless antenna, the accelerometer			Consist of central server, local ATS extension, local workstation, OCC workstation, maintenance workstation by DCS network
Da xing line	22	11	4	Axle counter equipment, beacon	VOBC	Train-ground communication through wireless access point	Three choose two in key parts	VOBC cabinet, TOD, speed sensors, proximity sensors, TI antenna, wireless antenna, the accelerometer			Consist of central server, local ATS extension, local workstation, OCC workstation, maintenance workstation by DCS network
Line 14	12/47.3	6/37	3月14日	Axle counter (Keanda)		Wireless LAN(802.11B)	2 Sets of ATP at head and tail,three choose two mode	On-board ATP/ATO cabinets, BTM receiving unit, the BTM antenna, speed sensors, radar speed sensor, automotive wireless receiver, human–computer interface, etc.			Consist of central server, local ATS extension, local workstation, OCC workstation, maintenance workstation by DCS network

system's updating and reforming staff, the company should integrate the modes, control the supplier's number at the minimum, up to three if possible, so that the competition mechanism and the management of operating company would be applicable.

(4) Solving the updating problem of signaling system's spare parts and electrical parts. There are many questions raised on the qualities of after-sales-service, while spare parts' consumption reaches a large amount. Here are some suggestions:

(1) Increase the percentage to 5–8 % in the contract of new lines. Purchase contractors' exclusively offered spare parts which are important for the normal operation, reduce the percentage of universal market available spare parts.

(2) If more than 5 % of spare parts stock out of the total amount of equipments cannot meet the operational needs during the guarantee period of quality, it indicates that the manufacturing facility has existing flaw in the design of the equipment which leads to the high fault rate and therefore needs to implement thorough change in design. The contract of the new line should stipulate it explicitly.

(3) There are many electrical parts in signaling system equipments, and these parts have a high rate of replacement. In the new line contract, it should be stipulated that substituting products fitted for the system's demand should be provided by manufacturers during product's life-cycle period, and the substitution should be compatible with the former product.

(4) Operating company should make regular contact with the manufacturer, and ascertain the availability of spare parts for the next five years. As for the equipments which may encounter production halt, the company should initiate researching, testing, and purchasing work of the substituting products in advance.

(5) Enhance the research facilities of signaling system's fault warning, maintenance, and faultand-failure analysis. Add online real-time monitoring aids, especially the condition-monitoring method related to crucial signal equipments to strengthen system's fault prevention and warning function. To ensure working quality, the company should promote thematic study of repair and maintenance after the expiry of the manufacturer's quality-guarantee period. Initiate analytic research of signal fault's influence on transportation to improve the system's ability of identifying faults.

(6) Establishing a professional signaling system's maintenance team which is status wise stable, strength wise adequate, and technique wise experienced. Set up specialized personnel-training base. Enhance the team by institutional support and payment guarantees, such as institute setup, personnel ability, age structure, working age limit, technical grade to ensure the safe operation of subway.

(7) Promoting the engineering application of the signaling system which is researched and developed independently. At present, many CBTC (communications based train control) signaling systems produced by many domestic manufacturers are applied to many engineering projects in a mature manner. Domestication and engineering application should be propelled sustainably. In the future, according to related industrial policies, a certain domestication rate of signaling system should be required. In the bid-evaluation criteria, suppliers with multiple lines of CBTC operating performance should be given certain preference.

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